LT Katharine Shobe, USN, Vance Kinsey, and Barbara Wyman, Ed.D.

Identifying Human Performance Problems in a Submarine Environment Utilizing the Human Factors Analysis and Classification System (HFACS) Framework

ABSTRACT

A program to develop a proactive, systematic method to identify and correct human performance problems in the Submarine Force is presented. Specifically, the effectiveness of several two-person accountability programs is investigated to determine if systemic problems exist and what solutions are available to correct these deficiencies. The goal is to identify and document the barriers and error probability for several submarine two-person procedures, such as rig for dive and navigation chart review. Data collection on the occurrence of human factors present in these programs suggests a commonality of causal factors in performance problems. The DoD Human Factors Analysis and Classification System (HFACS) was modified for submarine application to standardize the method to collect, categorize, and compare these factors. Subject matter experts were interviewed in order to assess the frequency of occurrence of the factors contained within HFACS for the submarine programs. Results indicate that the common factors across the programs span organizational factors, supervision, preconditions, and acts, with the majority falling under the preconditions category. In the next project phase, the human error probability will be determined for each factor. Using effective intervention techniques the odds can be improved of preventing an event by attacking the errors that have the greatest potential of resulting in an event.

INTRODUCTION

This paper describes a program to develop a proactive, systematic method to identify and correct human performance problems in the Submarine Force. Commander Submarine Force Pacific (COMSUBPAC) identified issues with the effectiveness of several two-person accountability programs, and the effort described in this paper investigates these programs to determine if systemic problems exist and provides recommendations to correct these deficiencies. Two-person accountability programs are those programs and processes within the Submarine Force that are deemed so important that two qualified personnel are required to perform essential actions to minimize the possibility of error. Improper actions, failure to correctly perform the procedure or strictly adhere to applicable processes could result in a loss of control of classified information, unsafe conditions resulting in equipment damage, personal injury or death, or lead to improper operation of critical equipment affecting submarine safety, operation and mission capability. The five programs that have been specifically designated for investigation include rig for dive, tag out system, navigation chart review, Reactor Control (RC) Division Preventive Maintenance System (PMS), and Electronic Key Management System (EKMS).

A preliminary background investigation to determine if systemic flaws exist in these programs indicated that all of the programs are designed to minimize the possibility of human error

resulting in an "event," such as a mishap, incident or accident. Based on the comparison of high-risk industry processes, the event is undesired; therefore "Event Free" is the goal of preventing mishaps. Research has consistently concluded that human error will occur. The goal, then, is to build defenses so the system is either error tolerant or errors can be detected and corrected before they cascade into an event. Some of these defenses are built into the process of actually performing work (known as active conditions) and other defenses are built into the entire system within which the performers work (known as latent conditions). The figure below, adapted from research conducted by Reason (1990), illustrates these points.
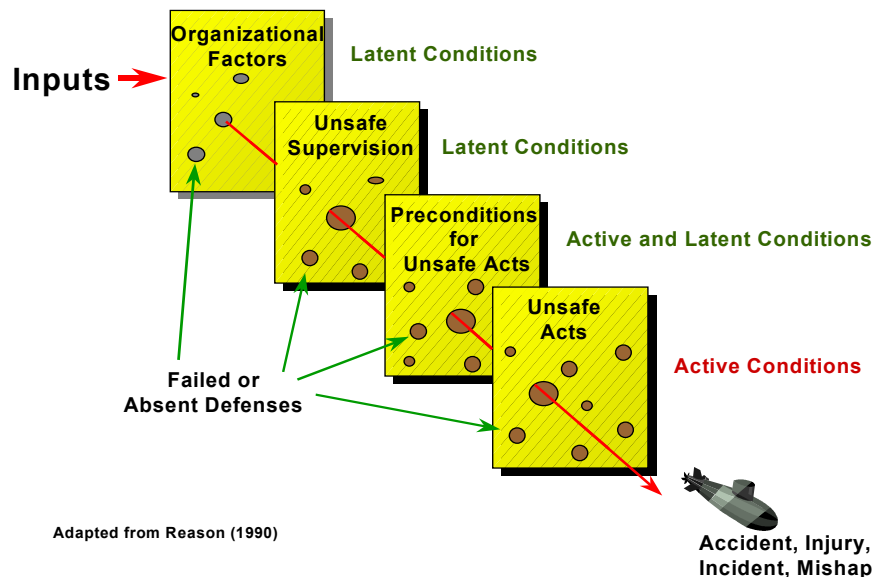

Adapted from Reason (1990)

FIGURE 1. Depiction of Reason's Model of Human Error

Typically, identification of human performance errors comes to light after a mishap. An example of this approach is instantiated in the Human Factors Analysis and Classification System (HFACS). The HFACS was developed by the Department of Defense (DoD) to assist in determining the human causes of aviation mishaps after it was demonstrated that 80 percent of all flight accidents in the Navy and Marine Corps were caused by human error. Application of the tool, HFACS, now offers assistance in the investigation process, along with targeting training and prevention. Other military organizations such as the Army and Air Force have also adopted the HFACS in their efforts to combat human error.

The current investigative approach is to identify and document the barriers and error probability for each of the two-person accountability programs identified earlier. The same information is gathered from two other Navy programs that have been nominally designated "exemplar" programs: Strategic Weapons Maintenance and Aircraft Maintenance procedures. These programs are then compared and contrasted to determine differences in the system of error prevention barriers, including the probability of error contribution to events and frequency of performance/error metrics. Finally, recommendations will be made as to which barriers should

be corrected for each of the programs and determine if there are systemic (organizational) issues that must be addressed. This report describes the identification and modification of the data collection tool, HFACS, outlines the process of data collection, and presents the results for the two person accountability programs. HFACS meets the criteria for the type of data needed for the current effort because it is based on Reason's model. First the instrument and the model it is based upon are described, and then the modifications for the current effort are described.

MODEL OF HUMAN ERROR

In an effort to develop a tool to use proactively, vice retroactively, the DoD HFACS is currently being adopted for use in the Submarine Force. This framework for identifying and analyzing human error is based on Reason's (1990) model of latent and active failures. Before outlining the process and application of the Submarine HFACS, Reason's model is briefly reviewed.

Reason (1990) developed a framework that describes four levels of human failure, with each level influencing the other. The four levels of are 1) unsafe acts, 2) preconditions for unsafe acts, 3) unsafe supervision, and 4) organizational influences. The first level, unsafe acts, refers to active failures that are based on human error, and is where most accident investigations have traditionally focused their efforts. However, latent failures comprise the next three levels of the framework and are included in the causal sequence of events. This model is referred to as the "Swiss Cheese" model, because accidents happen when the holes in the cheese are aligned.

As described by Reason (1990), *active failures* are the actions or inactions of operators that are believed to cause the mishap. Traditionally referred to as "error", they are the last "acts" committed by individuals, often with immediate and tragic consequences. In contrast, *latent failures* or *conditions* are errors that exist within the organization or elsewhere in the supervisory chain of command that effect the sequence of events characteristic of a mishap. Viewed from this perspective then, the actions of individuals are the end result of a chain of factors originating in other parts (often the upper echelons) of the organization. The problem is that these latent failures or conditions may be undetected for a period of time from hours to months, until they finally adversely affect the operation.

HFACS's taxonomy, based on Reason's model (1990), includes the four tiers of human failure from that model: 1) unsafe acts, 2) preconditions for unsafe acts, 3) unsafe supervision, and 4) organizational influences. Associated with each main tier are subcategories (see Figure 2), and the subcategories are broken down even further (for a total of 144 "Nanocodes" not represented in Figure 2).

Human Factors Analysis and Classification System (HFACS)
HFACS was designed for use as a comprehensive event/mishap, human error classification, data identification, analysis and classification tool. It is currently being used by the Naval Safety Center as a mishap investigation tool since it was designed for use by members of an investigation board in order to accurately capture and recreate the complex layers of human error in context with the individual, environment, team and mishap or event. Thus far HFACS has only been applied in the aviation domain in a retroactive manner. Given space constraints, the reader is directed to the following resources for more detailed information on Reason's model and HFACS: Reason (1990) and Wiegmann and Shappell (2003).
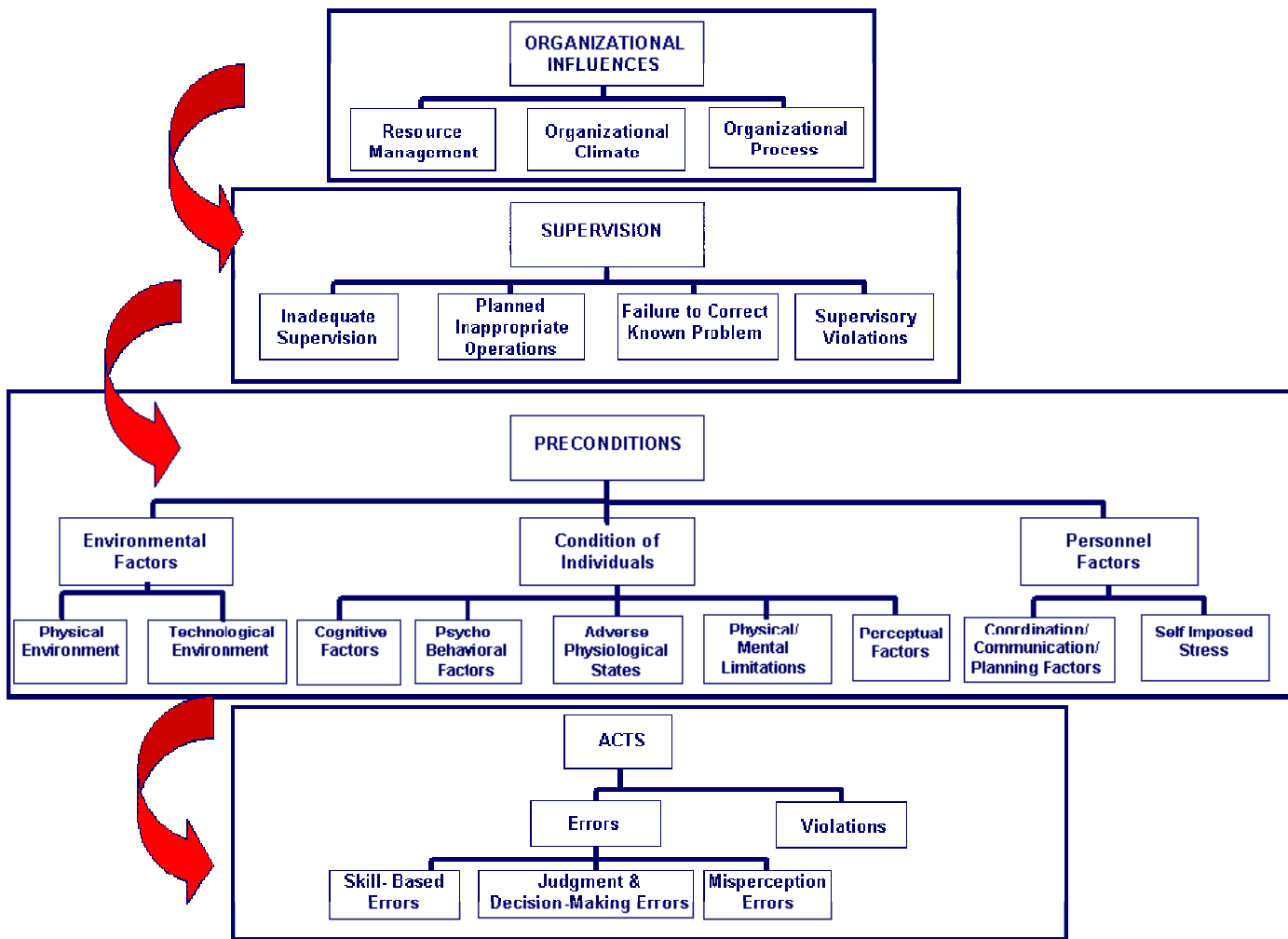
FIGURE 2. HFACS categories and subcategories

The investigation process then endeavors to identify the "holes (*hazards*) in the cheese" (see Figure 1). These hazards are identifiable because each mishap is not unique from its predecessors. In fact, most mishaps have very similar types of causes. They are due to the same holes in the cheese, so to speak. The hazards identified in each new mishap are not unique to that mishap. Therefore, if these system failures/hazards or "holes" are known, their roles in mishaps can be better identified -- or better yet, detect their presence and develop a risk mitigation strategy correcting them before a mishap occurs. For more detailed definitions of the individual factors, or Nanocodes, the reader is directed to the Naval Safety Center website on HFACS at http://www.safetycenter.navy.mil/hfacs/default.htm.

METHODOLOGY
Instrument
Traditionally human performance problems only become apparent after the problem appears (e.g., Shobe & Severinghaus, 2004). Detection and correction of these problems before they become causal factors in mishaps would provide a valuable service to all communities. Given

the demonstrated reliability and comprehensiveness of the HFACS (Wiegmann & Shappell, 2001), that tool was used as a starting point for the current effort. Since DoD HFACS was developed for aviation and some definitions are aviation-specific, it was reviewed and modified to accommodate submarine operations. HFACS was reviewed and modified to accommodate submarine operations. The integrity of the modified instrument was based on knowledge acquisition interviews and testing with Subject Matter Experts (SME)s. The instrument was then validated with a new group of SMEs. The final instrument contained all but three of the original Nanocodes (e.g., "inadequate anti-G straining maneuver" was removed), and five of the original definitions were revised to make them less aviation-specific. The DoD HFACS contains 147 Nanocodes, while the revised version for submarine operations contains 144 Nanocodes. The final tool set developed includes 1) verbal interview questions, 2) a survey format, and 3) a database structure that could be used as an analyst checklist.

Data Collection
In the current effort the interview version of the Submarine HFACS was used. The goal was to determine how often the different factors (e.g., Nanocodes) occur during the submarine operations of rig for dive, tag out system, navigation chart review, RC Dvision PMS, and EKMS. For each Nanocode a question was formed to capture the definition and ask how often it occurs during that event (e.g., How often is a crew member rushed when performing a task?). The interview was not tied to any specific program so it could be applied to all of them. After each question the SME answered on a scale of 1 to 5 how often that event occurs: 1) never, 2) rarely, 3) sometimes, 4) often, and 5) always. SMEs were provided a sheet of paper with the name of the relevant submarine program and the response scale to refer to during the interview.

For each submarine program, five SMEs were interviewed for a total of 25 interviews. The inclusion criteria was the person had to have performed the job within the past six to twelve months and be qualified if relevant. For the benchmark programs of Strategic Weapons Maintenance and Air Maintenance five SMEs were also interviewed, respectively, adding 10 more interviews. The length of the interview was approximately 45 minutes per person. If two SMEs were available at one time, they would be interviewed concurrently.

RESULTS
Distribution of Data
Given the small sample size, an analysis of the response distributions was first conducted to determine whether a variable is substantially non-normal. The current data were subjected to an analysis of skewness and kurtosis. The responses usually followed a normal distribution, although some were clipped. This visual and statistical inspection of the data provided confidence in the appropriateness of using means and standard deviations for the data set. If the distributions had been more different (e.g., skewed, bimodal, etc.), using these measures of central tendency and dispersion would be inappropriate and meaningless. However, given the small sample size, inferential statistical analyses were not conducted, only descriptive statistics.

Submarine Programs
Results are presented from the most general HFACS categories to the more specific subcategories. First the results for the HFACS Category by Submarine Program analysis are presented, then the HFACS Subcategory results, and finally the overall Nanocodes common

across the programs. For all of the Nanocode response means by individual programs please contact the authors.

The means for the four HFACS categories of Acts, Preconditions, Supervision, and Organizational were determined for the five submarine programs (Rig for Dive, Tag Out System, EKMS, RC Division PMS, and Navigation Chart Review). Figure 3 depicts these results.

The results in Figure 3 indicate that when the overall categories are used (e.g., Acts), ratings of occurrence for the various factors were low. To get a more informative analysis, data were next analyzed for each Nanocode, or factor. A better picture of the data is revealed in Figures 4 and 5 on the following two pages, which depict the mean ratings for the subcategories.
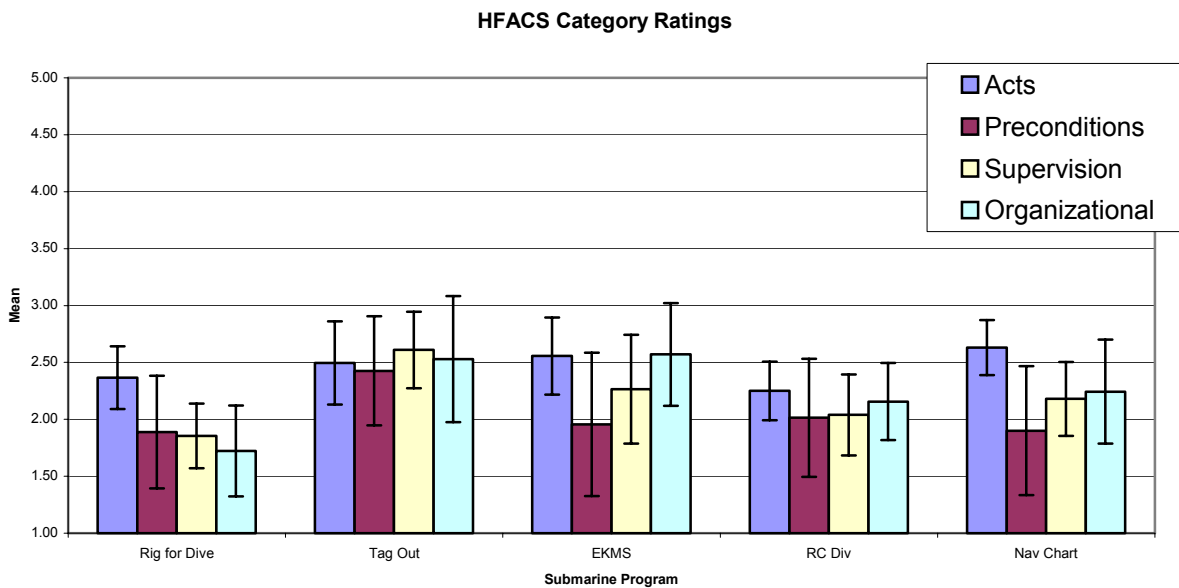

FIGURE 3. Mean Ratings for HFACS Acts, Preconditions, Supervision, and Organizational categories (Note: Responses range from 1-5).

Identifying Human Performance Problems in a Submarine Environment Utilizing the Human Factors Analysis and Classification System (HFACS) Framework
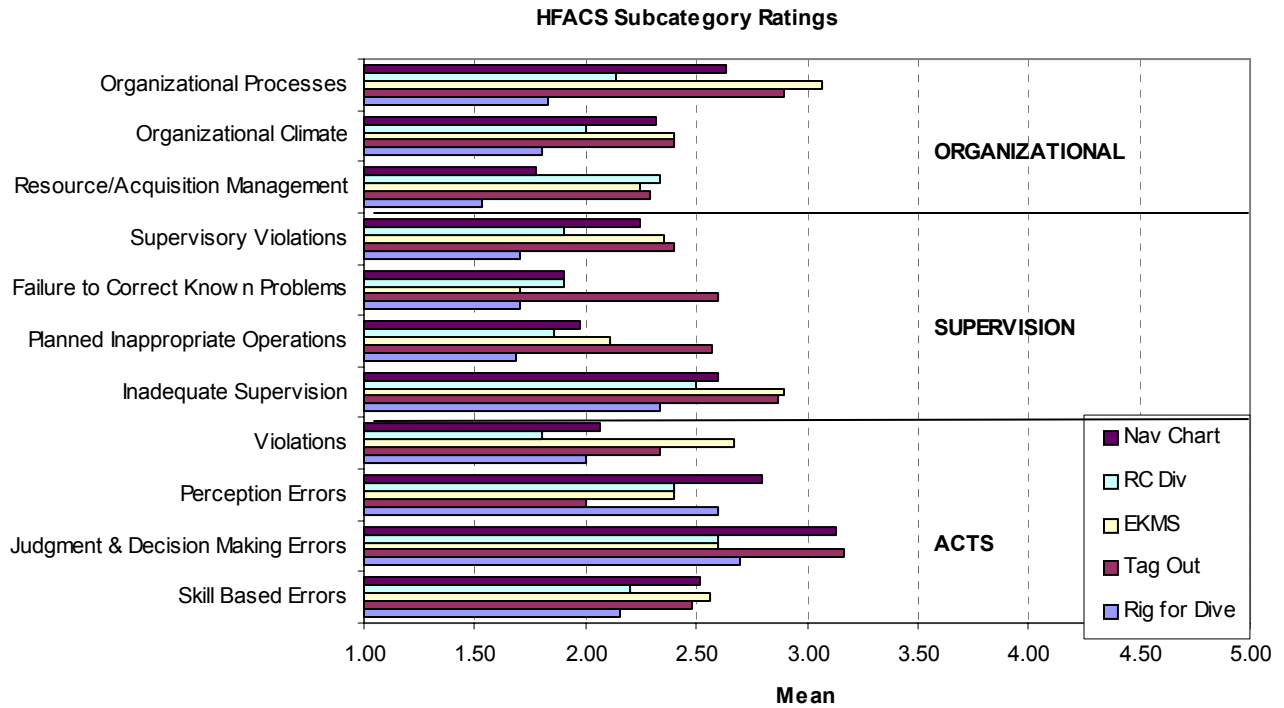

HFACS Subcategory Ratings

FIGURE 4. HFACS subcategory means for submarine programs (Note: Responses range from 1-5).

HFACS Subcategoy Ratings
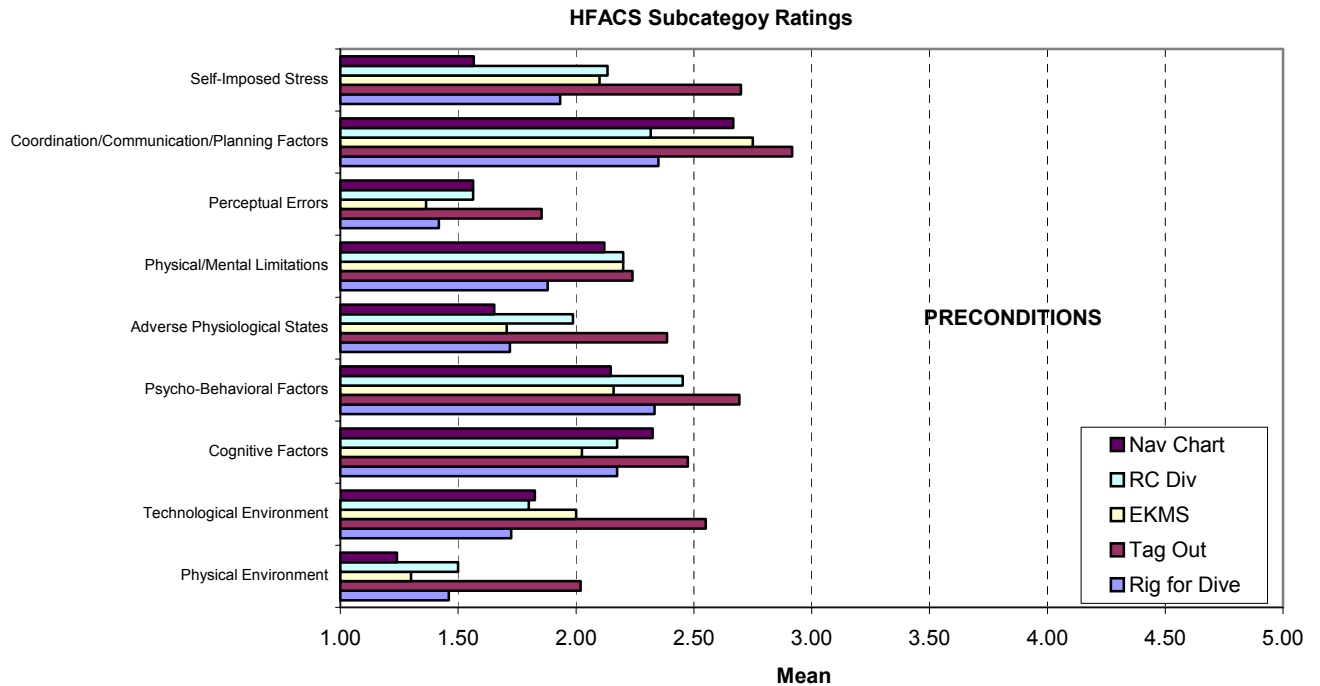
FIGURE 5. HFACS subcategory means for submarine programs (Note: Responses range from 1-5).

With the more detailed analysis of the subcategories, it appears that the subcategories of Judgment and Decision-Making Errors, Inadequate Supervision, Organizational Processes, and Coordination/Communication/Planning Factors are consistently rated highly in the five programs, which span all of the major categories. Interestingly, though, in the next analysis it is found that specific Nanocodes within different subcategories are ranked highly. For example, even though in the analysis in Figures 4 and 5 the subcategory of Adverse Physiological States is not rated highly, when the individual Nanocodes that make up that subcategory are examined, several of them are rated highly. It appears that an analysis that focuses on only the Categories or Subcategories to the exclusion to the Nanocodes misses important data and diagnostic information.

The graphed data for each individual Nanocode is not presented due to space constraints, but the findings are summarized. Looking at the rate of occurrence of the specific Nanocodes (the 141 factors) for the submarine programs individually, the top 10 ranked Nanocodes across all five programs collapsed are presented in Table 1.

TABLE 1. Top 10 Ranked Nanocodes By Submarine Program

Rank	Nanocode	Code	Number of times in top ten	Mean
1	Circadian Rhythm Desynchrony	PC308	5	3.92
2	Necessary Action – Rushed	AE203	4	3.56
3	Necessary Action – Delayed	AE204	4	3.04
4	Motivational Exhaustion (Burnout)	PC215	4	3.24
5	Fatigue - Physiological-Mental	PC307	4	3.44
6	Inadequate Rest	PP205	4	3.24
7	Local Training Issues-Programs	SI003	4	3.08
8	Ops Tempo-Workload	OP001	4	3.28
9	Complacency	PC208	3	3.08
10	Standard-Proper Terminology	PP107	3	3.12

Given the small sample size and minor mean differences, the ranking data may be more appropriate and meaningful than the means data. Table 1 also reveals that the top ranking individual Nanocodes are not necessarily accounted for in the Category and Subcategory conclusions presented earlier. When categorized per the HFACS hierarchy, the classifications that emerge for the most frequently occurring factors across the programs of rig for dive, EKMS, tag out system, RC Division PMC, and Navigation Chart Review are shown in Figure 6.
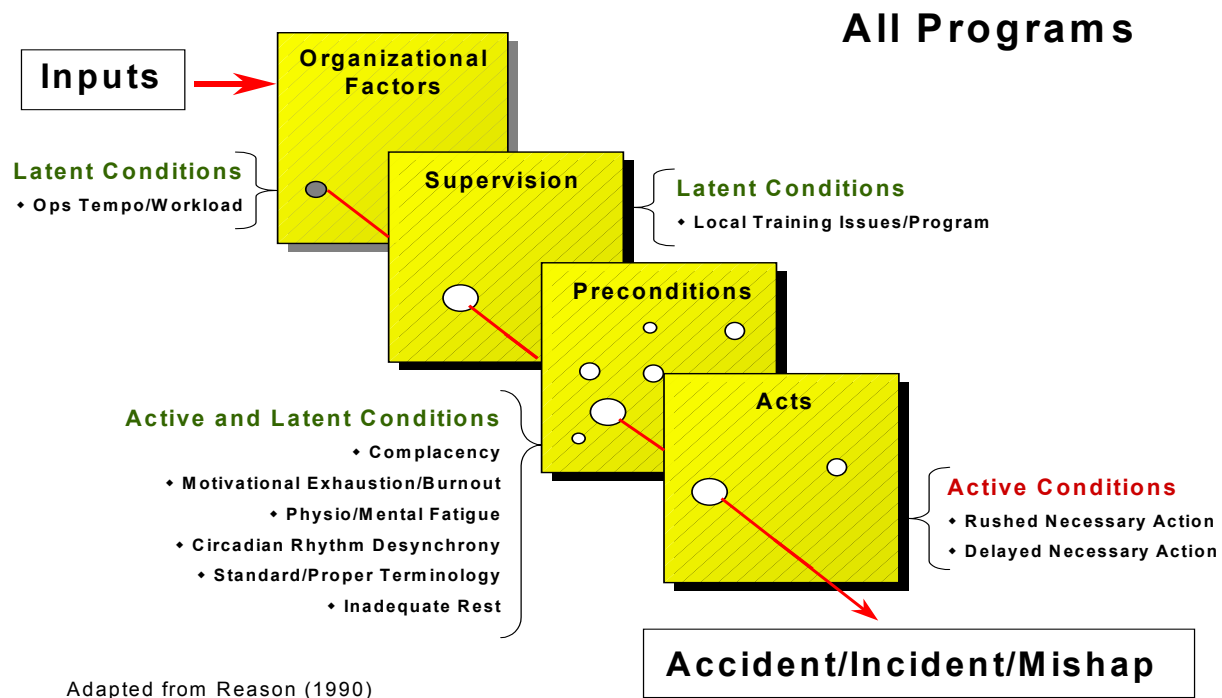
FIGURE 6. Submarine Results interpreted according to Reason's model.

Data from the exemplar programs is not presented in this paper.

CONCLUSION

The goal of this phase of the project is to identify common factors, or barriers, that hinder human performance. The current effort used HFACS and SMEs to identify the most commonly occurring factors for the submarine programs rig for dive, tag out system, EKMS, RC Division PMS, and navigation chart review. The results of the current project provide insight regarding the occurrence of the various factors that contribute to performance problems. These factors can now be targeted for improvement or removal of the barriers. The next step is to extend the investigation beyond the rate of occurrence of the factors to the impact of the factors. This should be interpreted in conjunction with the error probabilities of the programs, with the result being a measure of error probability impact and priority matrix.

In a parallel effort, Commodore Submarine Squadron 2 (CSS 2) supports an initiative to use HFACS during submarine critiques and incidents, review of past Mishap Investigation Reports, and during all future Submarine mishap investigations. In conjunction with the CSS 2 initiative, this work will instill a culture of human performance awareness and improvement, accurate self-assessment processes, and proactive risk management in the Submarine Force. Ultimately the benefit may be realized in fewer human performance problems demonstrated by a reduction in accidents and mishaps.

REFERENCES

Reason, J., "Human Error," New York: Cambridge University Press, 1990.

Shobe, K., & R. Severinghaus, "Submarine Operations – New Technology Insertion Impacts on the Practice of Navigation & Piloting," *Undersea Human Systems Integration Symposium Proceedings*; Newport, RI, 2004.

Wiegmann, D.A., & S.A. Shappell, "Applying the Human Factors Analysis and Classification System (HFACS) to the Analysis of Commercial Aviation Accident Data," Presented at the *11th International Symposium on Aviation Psychology*: Columbus, OH, 2001.

ACKNOWLEDGMENTS

Katharine Shobe, Ph.D., LT, MSC, USN, *is a research psychologist at the Human Performance Center Detachment at the Submarine Learning Center and Commander, Submarine Force in Groton, CT. At the detachment she is responsible for conducting human performance improvement projects and training effectiveness evaluations, while pursuing her research interests in human performance and decision-making. She received her Ph.D. in cognitive psychology from Yale University.*

Vance Kinsey, M.Ed., *is a performance analyst at the Human Performance Center Detachment at the Submarine Learning Center and Commander, Submarine Force in Norfolk, VA. He is responsible for leading human performance projects dealing primarily with adult workforce development and organizational influence improvement, and retired from the US Navy following a career in the submarine community*

Barbara Wyman, Ed.D., *is a performance analyst at the Human Performance Center Detachment at the Submarine Learning Center and Commander, Submarine Force in Groton, CT. She received her Ed.D. in human development from Harvard Graduate School of Education.*